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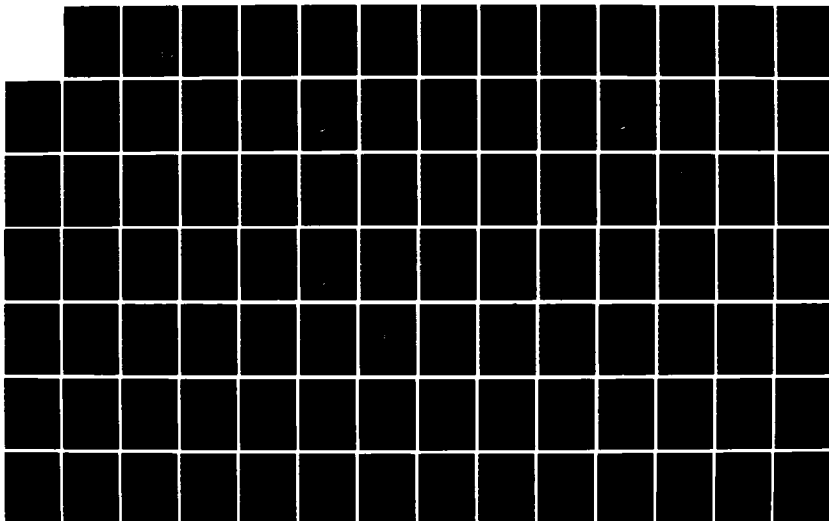
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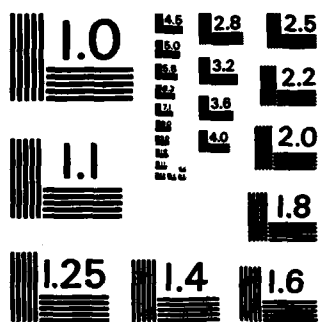
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HANGAR HEATING AND ENERGY CONSERVATION MANUAL

By

J. L. Ashley

September 1984

HEADQUARTERS AIR FORCE ENGINEERING AND SERVICE CENTER
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HANGAR ENERGY CONSERVATION MANUAL

INTRODUCTION

Hangars are large structures that require large amounts of energy for space heating. Headquarters Air Force Engineering and Service Center and the Naval Facilities Engineering Command funded a joint Air Force/Navy hangar heating investigation that was conducted by the Naval Civil Engineering Laboratory. This Manual is one of the results of the joint investigation.

The Hangar Energy Conservation Manual is organized into three sections: Section 1, Hangar Energy Conservation Survey Techniques; Section 2, Technical Option Sheets; and Section 3, General Equations. Section 1, Survey Techniques, is a checklist to be used in a hangar energy survey that is cross referenced to the applicable energy conservation Option Tech Sheets (Section 2). Each Tech Sheet presents a description of an energy conservation option, application feasibility criteria, survey data requirements, procedure to calculate the annual energy savings available, option life expectancy and estimated installation cost. Section 3 is equations associated with the energy conservation Option Tech Sheets, which can be used to increase the accuracy of the annual energy savings projected by the Tech Sheets.

Four appendixes are contained in this manual. Appendix A provides information required for designers to install or design a destratification system, Appendix B provides criteria to estimate lighting system energy savings, Appendix C provides thermal properties of materials and fuel heat values, and Appendix D provides national weather data.

The procedures presented in this manual provide methods to quickly estimate the results of hangar energy conservation options. Other methods are available that produce similar results and can be utilized if so desired. Although this Manual was written for hangars, the procedures can be used for most large industrial buildings and warehouses that must be heated.

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SECTION I - SURVEY TECHNIQUES

SURVEY TECHNIQUES

A hangar survey should be conducted in a systematic manner. The following seven areas need to be inspected for discrepancies that cause excessive heat loss:

1. Hangar aircraft access doors
2. Vehicle access doors
3. Personnel access doors
4. Exterior walls
5. Roof
6. Windows
7. Heating system and controls

The location and physical characteristics of all discrepancies should be recorded. Survey guidelines, with suggested correction measures, are as follows:

Item	Reference
1. Aircraft access doors	
1.1 Door seal material: good bad rubber (replace with nylon brush seals)	Tech Sheet No. 9 Tech Sheet No. 10
1.2 Door alignment: good bad (realign)	Tech Sheet No. 12
1.3 Insulation: yes (____ inches, material) no (insulate)	Tech Sheet No. 1
1.4 Surface condition: good bad (repair, seal holes, etc.)	Tech Sheet No. 2
1.5 Aircraft appendage protrusions through doors: no yes (seal)	Tech Sheet No. 11
2. Vehicle access doors	
2.1 Are vehicle access doors installed: yes no (install)	Tech Sheet No. 13
2.2 Door seal condition: good bad (repair or replace)	Tech Sheet No. 9

- | | | | | |
|---------------------------|---------------------------------------|------------------|-----|-------------------|
| 2.3 | Surface condition: | good | bad | Tech Sheet No. 2 |
| | (repair, seal holes, etc.) | | | |
| 2.4 | Insulation: | yes (___ inches, | | Tech Sheet No. 1 |
| | material) | no (insulate) | | |
| 2.5 | Alignment: | good | bad | Tech Sheet No. 12 |
| | (realign) | | | |
| 2.6 | Flexible vinyl strip doors installed: | | | Tech Sheet No. 14 |
| | yes | no (install) | | |
| 3. Personnel access doors | | | | |
| 3.1 | Door seal condition: | good | | Tech Sheet No. 16 |
| | bad (repair or replace) | | | |
| 3.2 | Surface condition: | good | | Tech Sheet No. 9 |
| | bad (repair, seal holes, etc.) | | | |
| 3.3 | Door insulated: | yes | no | Tech Sheet No. 15 |
| | (insulate) | | | |
| 3.4 | Door frequently used: | no | | Tech Sheet No. 14 |
| | yes (install flexible vinyl | | | Tech Sheet No. 17 |
| | strip door, entrance vestibule, | | | Tech Sheet No. 18 |
| | or revolving door) | | | |
| 4. Exterior walls | | | | |
| 4.1 | Insulation: | yes (___ inches, | | Tech Sheet No. 1 |
| | material) | no (insulate) | | |
| 4.2 | Surface condition: | good | | Tech Sheet No. 2 |
| | bad (repair, seal holes, etc.) | | | |
| 4.3 | Floor/wall caulking: | yes | | Tech Sheet No. 3 |
| | no (caulk) | | | |
| 4.4 | Ceiling/wall caulking: | yes | | Tech Sheet No. 3 |
| | no (caulk) | | | |
| 5. Roof | | | | |
| 5.1 | Insulation: | yes (___ inches, | | Tech Sheet No. 1 |
| | material) | no (insulate) | | |
| 5.2 | Surface condition: | good | | Tech Sheet No. 2 |
| | bad (repair, seal holes, etc.) | | | |

6. Windows

- 6.1 Condition: good bad Tech Sheet No. 6
(replace broken, cracked, or missing panes)
- 6.2 Daytime electric lighting: no Tech Sheet No. 5
 yes (reduce window area by replacement with wall/door structural material or cover with insulation)
- 6.3 Double glazed or storm windows: Tech Sheet No. 7
 yes no (install double glazed or storm windows)
- 6.4 Will windows close and seal: Tech Sheet No. 8
 yes no (repair, replace seals, etc.)

7. Heating System

- 7.1 Aircraft access door shutoff switch: yes no (install shutoff switch) Tech Sheet No. 20
- 7.2 Temperature setback device: yes Tech Sheet No. 21
 no (install for off-shift periods)
- 7.3 Ceiling level temperature 10°F greater than floor level temperature: Tech Sheet No. 22
 no yes (destratify or Tech Sheet No. 26
install radiant heating system) Tech Sheet No. 27
 Tech Sheet No. 28
 Tech Sheet No. 29
 Tech Sheet No. 30
- 7.4 Central heating plant for all hangars: yes no (tune up hangar's boiler) Tech Sheet No. 23

8. Miscellaneous

- 8.1 Energy efficient lighting in hangar bay: yes no (install HPS lighting) Tech Sheet No. 25
- 8.2 Fluorescent office lighting: no Tech Sheet No. 24
 yes (reduce wattage)
- 8.3 Insulation between heated/cooled and non-heated/cooled interior partitions: yes no Tech Sheet No. 4
(insulate)
- 8.4 Vehicle loading dock: no Tech Sheet No. 19
 yes (install seals)

SECTION II - TECHNICAL SHEETS

EXTERIOR SURFACE INSULATION (Tech Sheet No. 1)

Description

Many hangars were constructed without wall or door insulation and very little roof insulation. Insulating exterior surfaces can save significant amounts of energy. In addition to reducing the amount of heat that is transmitted through the hangar walls and roof, insulation can also reduce air infiltration. Priority should be given to insulating exterior surfaces that have no insulation before adding insulation to surfaces with existing but substandard insulation.

Feasibility Requirements

Site specific but, in general, insulating exterior surfaces is feasible for all heated/cooled structures.

Survey Data Requirements

1. Average number of annual heating/cooling degree days; D_h and D_c , days-°F/yr
2. Area of exterior surfaces to be insulated; A , ft²
3. U value of existing exterior surface; U_e , Btu/ft²-°F-hr
4. U value of insulation to be added; U_i , Btu/ft²-°F-hr
5. Overall efficiency of heating/cooling system; e_h and e_c ; %±100.

Procedure

Calculate the average annual energy savings (AES) as follows:

$$AES = \frac{24 \times A \times D_h \times (U_e - U_i)}{e_h} + \frac{24 \times A \times D_c \times (U_e - U_i)}{e_c}, \text{ Btu/yr}$$

General Information

Life: 25 years

Installation Cost: Site specific

SEAL HOLES AND CRACKS IN WALLS AND DOORS (Tech Sheet No. 2)

Description

Often holes and cracks exist in hangar walls and doors caused by ground settling, corrosion, wind damage, and collisions. These holes and cracks provide a constant source for air infiltration and should always be repaired. Temporary patches can be made (duct tape, cardboard, etc.) until permanent repairs are done.

Feasibility Requirement

Always feasible for heated structures

Survey Data Requirements

1. Average number of annual heating degree days; D_h , days-°F/yr
2. Area of hole or crack; A , ft²

Procedure

Calculate the average AES from Figure 1 or as follows:

$$AES = 110 A D \sqrt{5,700 + D_h}, \text{ Btu/yr}$$

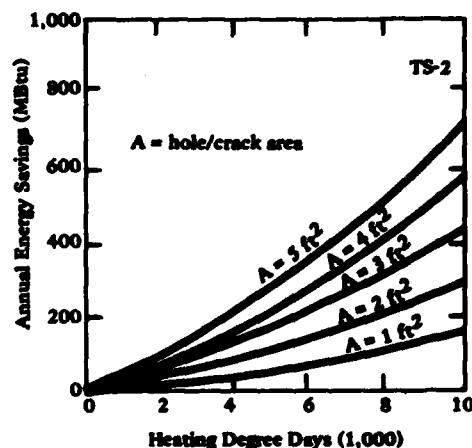


Figure 1. Annual energy savings for Test Sheet No. 2.

General Information

Life: Varies Installation Cost: Varies

SEAL WALL, FLOOR, AND ROOF CRACKS (Tech Sheet No. 3)

Description

The junction made when the wall of a hangar joins with the floor or roof is a source of air infiltration. A small crack exists at this junction that constantly lets cold outside air in and allows warm inside air to escape. This air infiltration source can be sealed by caulking the crack with one of many caulking materials available.

Feasibility Requirement

Always feasible for heated hangars.

Survey Data Requirements

1. Average number of annual heating degree days; D_h , days-°F/yr
2. Hangar perimeter less the width of aircraft access doors; L , ft

Procedure

Calculate the average AES from Figure 2 or as follows:

$$AES = 0.14 L D \sqrt{5,700 + D_h}, \text{ Btu/yr}$$

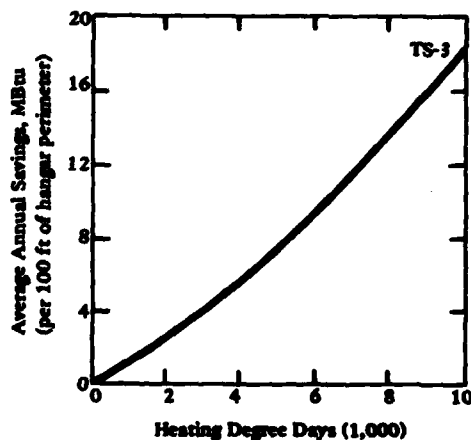


Figure 2. Annual energy savings for Tech Sheet No. 3.

General Information

Life: 10 years

Installation Cost: \$15/100 ft

INSULATE BETWEEN HEATED, COOLED, AND NON-HEATED SPACES (Tech Sheet No. 4)

Description

While a hangar's exterior wall may be insulated, internal partitions between spaces may not be. Hangar bays often adjoin air conditioned office spaces. Installing insulation between these partitions can save energy, Figure 3. A vapor barrier is required to prevent water condensation.

Feasibility Requirements

Site specific. Feasible for non-insulated partitions with at least a 10°F temperature difference on each surface for 180 days or more.

Survey Data Requirements

1. Partition area; A, ft²
2. Existing U value for partition; U_p, Btu/ft² - °F-hr
3. U value for insulation; U_i, Btu/ft² - °F-hr
4. Temperature difference across the partition; ΔT, °F
5. Duration of temperature difference; N, days/yr
6. Overall heating system efficiency; e, %±100

Procedure

Calculate the average AES as follows:

$$AES = \frac{24 A N}{e} (U_i - U_p) \Delta T, \text{ Btu/yr}$$

General Information

Life: 25 years

Installation Cost: Site specific

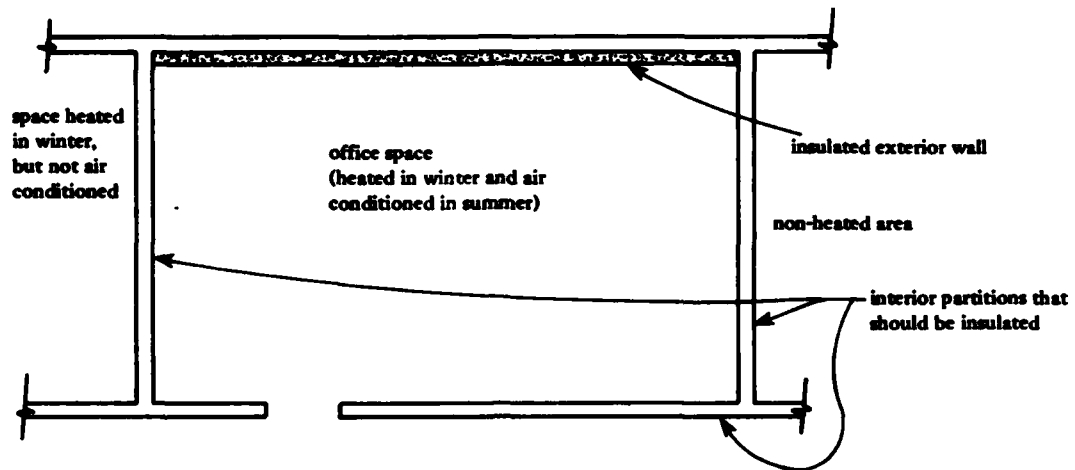


Figure 3. Hangar bay.

REDUCE WINDOW AREA (Tech Sheet No. 5)

Description

Glass windows have little insulating value and are sources of heat loss. Most activity in hangars on modern aircraft requires artificial light because natural lighting is insufficient. Reducing window area can reduce energy consumption when artificial lighting is required. Windows can be removed and replaced with wall sections or they can be covered with insulation.

Feasibility Requirements

Site specific, but reducing window area is feasible for all heated structures that require artificial interior lighting.

Survey Data Requirements

1. Average number of annual heating degree days; D_h , days-°F/yr
2. Window area to be reduced; A , ft²

Procedure

Calculate the average AES from Figure 4 or as follows:

$$AES = 5.8 A D_h \text{ Btu/yr}$$

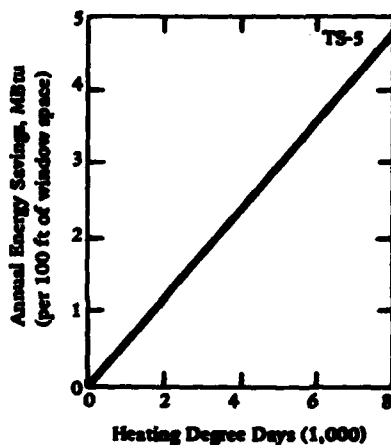


Figure 4. Annual energy savings for Tech Sheet No. 5.

General Information

Life: 25 years

Installation cost: Site specific

REPLACE BROKEN AND/OR MISSING WINDOWS (Tech Sheet No. 6)

Description

Infiltration of outside air into heated buildings is a major source of heat loss. Broken and/or missing window panes contribute greatly to air infiltration. Replacing broken or missing window panes should always receive a high priority as an energy conservation action.

Feasibility Requirement

Always feasible for heated structures.

Survey Data Requirements

1. Average number of annual heating degree days; D_h , days-°F/yr
2. Total area of broken or missing windows; A , ft²

Procedure

Calculate the average AES from Figure 5 or as follows:

$$AES = 110 D_h A \sqrt{D_h + 5,700}, \text{ Btu/yr}$$

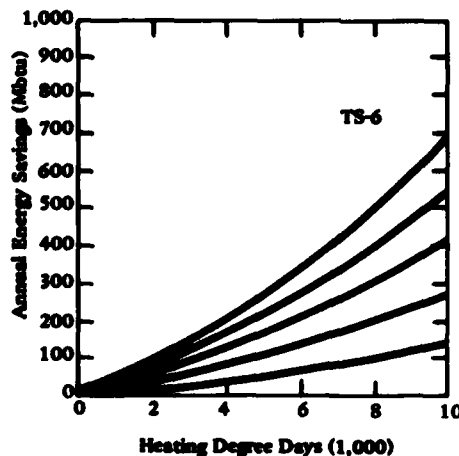


Figure 5. Annual energy savings for Tech Sheet No. 6.

General Information

Life: 15 years

Replacement cost: Variable

STORM AND DOUBLE GLAZED WINDOWS (Tech Sheet No. 7)

Description

Glass windows have little insulating value and are a heat loss source. Some hangars and other structures use windows to provide most of their interior lighting requirements. Adding storm windows or double glazed windows for natural lighting reduces the amount of heat loss and air leakage.

Feasibility Requirements

Feasible for heated structures in locations with 2,000 or more heating degree days.

Survey Data Requirements

1. Average number of annual heating degree days; D_h , days-°F/yr
2. Area of windows to be double glazed; A , ft²

Procedure

Calculate average AES from Figure 6 or as follows:

$$AES = 18 A D_h, \text{ Btu/yr}$$

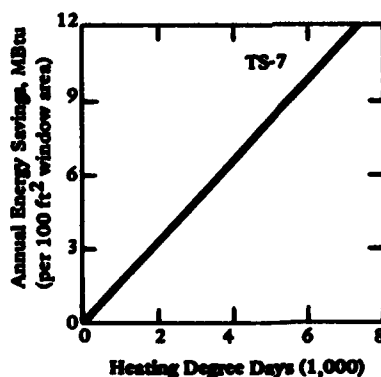


Figure 6. Annual energy savings for for Tech Sheet No. 7.

General Information

Life: 25 years

Installation Cost: Site specific

REPLACE WINDOW SEALS (Tech Sheet No. 8)

Description

Many hangar windows are opened during hot weather for ventilation. As time progresses, the windows do not seal tightly when closed and provide an air infiltration source. Often, operable windows were designed and installed with no seals or the seals have deteriorated. Adding or replacing window seals for can reduce air infiltration.

Feasibility Requirements

1. Marginally feasible for heated structures in locations with less than 2,000 heating degree days.
2. Always feasible for heated structures in locations with more than 2,000 heating degree days.

Survey Data Requirements

1. Average number of annual heating degree days; D_h , days-°F/yr
2. Length of window sealing required; L , ft

Procedure

Calculate the average AES from Figure 7 or as follows:

$$AES = 0.45 L D_h \sqrt{5,700 + D_h}, \text{ Btu/yr}$$

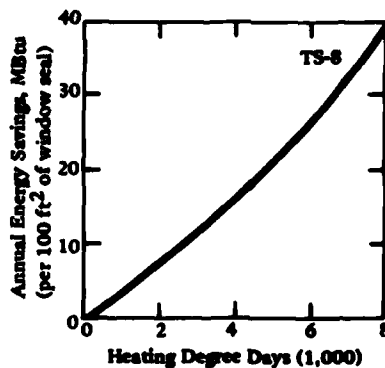


Figure 7. Annual energy savings for for Tech Sheet No. 8.

General Information

Life: 5 years
Cost: \$1.00/foot

REPLACE MISSING HANGAR DOOR SEALS (Tech Sheet No. 9)

Description

Hangar aircraft access doors are a significant percentage of the structure's total vertical surface area. These doors are usually located at each end of a hangar and consist of several panels that require a seal around the perimeter of each panel. Missing seals provide a major source of air infiltration. Rubber, fire hose, and nylon brush seals are available, but the nylon brush seals are preferred.

Feasibility Requirement

Always feasible.

Survey Data Requirements

1. Average number of annual heating degree days; D_h , days-°F/yr
2. Total area of unsealed crack around hangar door panels; A , ft²

Procedure

Calculate the average AES from Figure 8 or as follows:

$$AES = 105 A D_h \sqrt{D_h + 5,700}, \text{ Btu/yr}$$

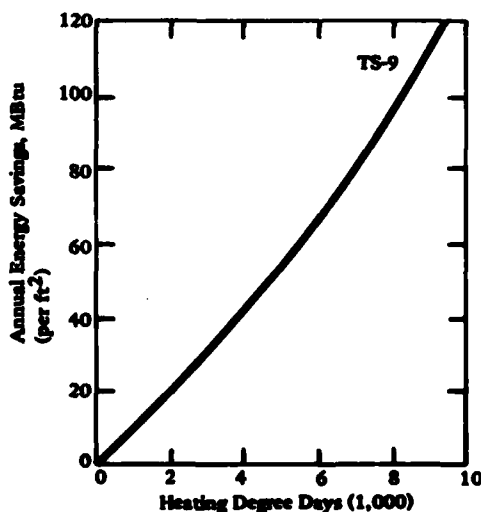


Figure 8. Annual energy savings for for Tech Sheet No. 9.

General Information

Life: (a) rubber = 2 years
(b) hose = 3 years
(c) nylon brush = 15 years
Cost: \$15-\$25/perimeter foot

NYLON BRUSH DOOR SEALS (Tech Sheet No. 10)

Description

Hangar aircraft access doors are a significant percentage of the structures total vertical surface area. These doors are usually located at each end of the hangar and consist of several panels that require a seal around their perimeter. Until recently only rubber or fire hose materials were available for hangar door seals. Nylon brush door seals are now available and are superior. These seals perform better and last longer than the rubber or fire hose seals. The nylon brush seal can conform to abrupt changes in surface contours and its resistance to weathering is much greater. These seals are easy to install, require no special tools, and are within the capabilities of most military bases.

Feasibility Requirement

Feasible for all heated hangars.

Survey Data Requirements

1. Average number of annual heating degree days; D_h , days-°F/yr
2. Total door seal length; L , ft

Procedure

Calculate the average AES from Figure 9 or as follows:

$$AES = 1,300 L D_h, \text{ Btu ft/yr}$$

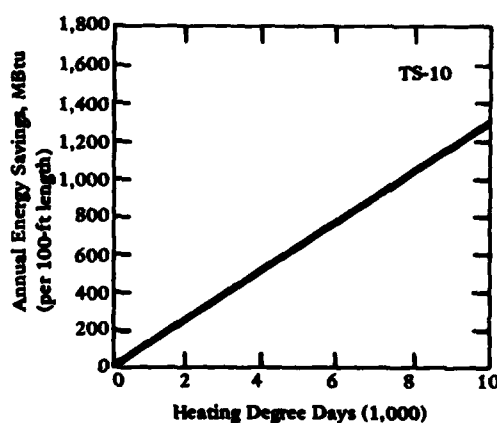


Figure 9. Annual energy savings for
for Tech Sheet No. 10.

General Information

Life: Unknown, but estimated 10 to 15 years
Installation Cost: \$15 to \$25/foot

AIRCRAFT APPENDAGE SEALS FOR AIRCRAFT SHEDS (Tech Sheet No. 11)

Description

Sheds that do not house an entire aircraft are found at many military installations. Tail surfaces protrude through a cutout in the hangar door. Vinyl/canvas material with draw strings or flexible vinyl strip doors are used to seal the gap between the aircraft and the hangar surfaces. These seals are subjected to heavy use and are often damaged. Improperly used or damaged aircraft appendage seals are a source of hangar air infiltration, and they should be repaired or replaced. Hangar crews should be instructed in the importance of properly using aircraft appendage seals. Flexible vinyl strip doors do not seal as well as the canvas or vinyl seals with draw strings, are more expensive, and are not preferred for use as aircraft appendage seals.

Flexibility Requirement

All heated aircraft sheds.

Survey Data Requirements

1. Average number of annual heating degree days; D_h , days-°F/yr
2. Total gap area between aircraft appendage and hangar structure; A , ft²

Procedure

Calculate the average AES from Figure 10 or as follows:

$$AES = 105 A D_h \sqrt{D_h + 5,700}, \text{ Btu/yr}$$

General Information

Life: 3 to 5 years

Installation Cost: \$500 to \$1,000/seal

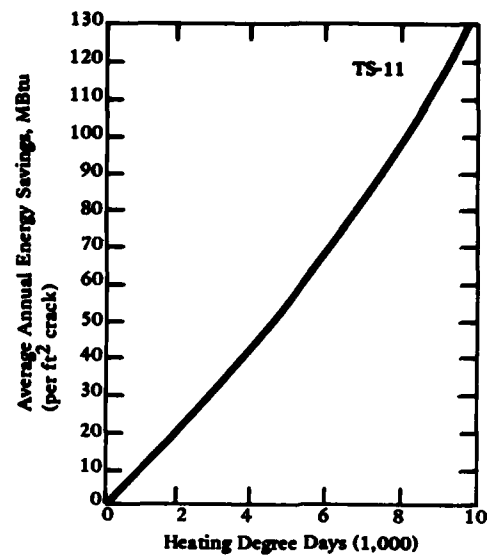


Figure 10. Annual energy savings for Tech Sheet No. 11.

MISALIGNED HANGAR DOORS (Tech Sheet No. 12)

Description

Hangar door alignment is critical if door seals are to reduce air infiltration. Misaligned doors can prevent a tight seal and create air infiltration sources. Improper door installation and/or settling effects are major sources of misaligned doors. Correcting this problem is site specific and can be expensive. An economic analysis is recommended to determine the cost effectiveness of a proposed hangar door alignment project.

Feasibility Requirement

Site specific.

Survey Data Requirements

1. Average number of annual heating degree days; D_h , days-°F/yr
2. Total area of crack resulting from misaligned doors; A , ft²

Procedure

Calculate the average AES from Figure 11 or as follows:

$$AES = 105 A D_h \sqrt{D_h + 5,700}, \text{ Btu/yr}$$

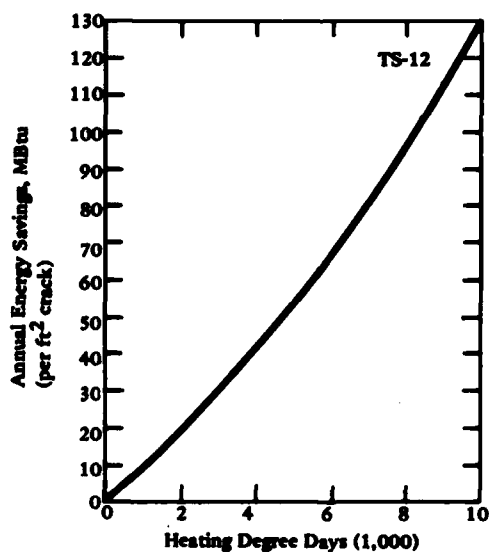


Figure 11. Annual energy savings for Tech Sheet No. 12.

General Information

Life: Site specific
Cost: site specific

VEHICLE ACCESS DOORS (Tech Sheet No. 13)

Description

Vehicles enter and leave hangars many times during the working day. Most hangars do not have a separate door for vehicles; thus, the hangar aircraft access doors are used. Usually these doors are opened 15 to 20 feet for 1 to 2 minutes per vehicle passage. During this time warm interior air is displaced by cold outside air. The installation of a separate vehicle access door can save energy by reducing the area of the opening required for vehicular traffic.

The retrofit of vehicle access doors in hangars is difficult. A wall is the preferred location; however, hangar design or usage usually requires that the vehicle door be installed in a hangar's aircraft access door. Retrofit of a vehicle access door in a hangar's aircraft access door must be done in such a way that maintains the door's structural rigidity. Overhead and roll-up doors have experienced alignment problems when retrofitted in hangar aircraft access doors. Vertically hinged doors are not alignment critical and should be considered if maintaining the rigidity of hangar aircraft access doors is critical (Figure 12).

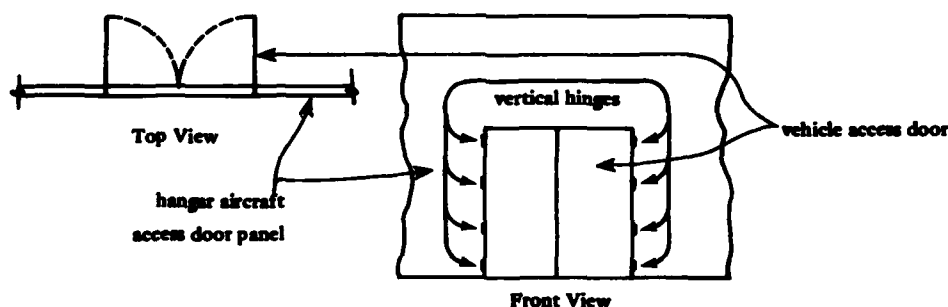


Figure 12. Vertically hinged vehicle access door.

Feasibility Requirement

See Figure 13.

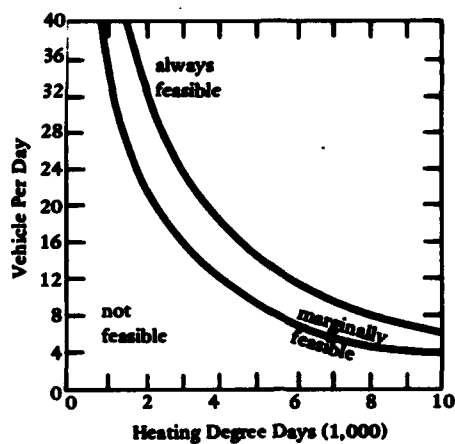


Figure 13. Feasibility requirement.

Survey Data Requirements

1. Average number of vehicles per day; P, 1/day
2. Average number of annual heating degree days; D_h, days-°F/yr

Procedure

Calculate average AES from Figure 14 or as follows:

$$AES = 48 D_h P \sqrt{D_h + 5,700}, \text{ Btu/yr}$$

General Information

Life: 25 years

Installation Cost: \$2,000 to \$40,000

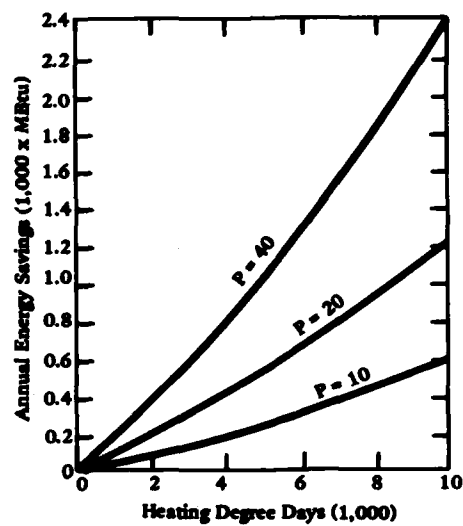


Figure 14. Annual energy savings for Tech Sheet No. 13.

FLEXIBLE VINYL STRIP DOORS (Tech Sheet No. 14)

Description

Flexible vinyl strip doors provide a method to reduce air infiltration for frequently used personnel and vehicle doors. Used properly vinyl strip doors can be very valuable, however, precautions should be taken to eliminate potential safety hazards connected with some applications. Vinyl plastic produces dense smoke when burning. Fire retardant vinyl should be used in order not to block doors during the early stages of a fire. Another hazard associated with flexible vinyl strip doors is their reaction to very high winds (in excess of 35 miles per hour). Personnel injuries have occurred during high winds, from hanging the vinyl strips wrong, and using the wrong weight of vinyl material. Care should be used for installations where foreign object damage could occur from small pieces of the door, which can break off a strip, or for applications where static electricity could present a fire hazard (explosion) or damage equipment.

Feasibility Requirement:

Site specific.

Survey Data Requirements

1. Average number of annual heating degree days, D_h , days-°F/yr
2. Average daily time door is in use; P , hr/day
3. Area of door, A ; ft²

Procedure

Calculate the average AES from Figure 15 or as follows

$$AES = 500 (P A D_h), \text{ Btu/yr}$$

General Information

Life: 5 years

Installation cost: Site specific (approximately \$8.00/ft²)

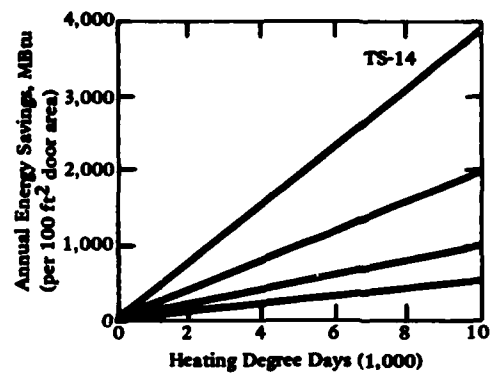


Figure 15. Annual energy savings for
for Tech Sheet No. 14.

INSULATE HOLLOW STEEL EXTERIOR DOORS (Tech Sheet No. 15)

Description

Hollow steel doors are used for personnel and other entrances in many hangars and similar structures. Filling the hollow space in these doors with urethane foam insulation can reduce the energy transmitted through the door. Small holes can be drilled into one side of the door and the foam forced in.

Feasibility Requirements

Always feasible for heated structures.

Survey Data Requirements

1. Average number of annual heating degree days; D_h , days-°F/yr
2. Area of doors to be insulated; A , ft²

Procedure

Calculate average AES from Figure 16 or as follows:

$$AES = 25 A D_h, \text{ Btu/yr}$$

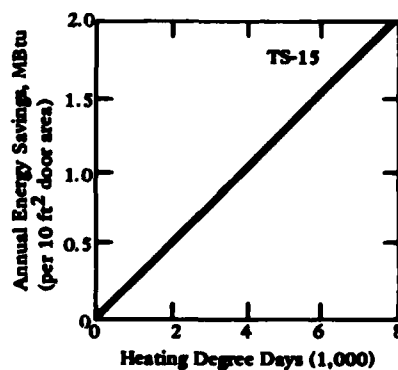


Figure 16. Annual energy savings for Tech Sheet No. 15.

General Information

Life: 25 years

Installation Cost: \$3.00/ft²

PERSONNEL DOOR SEALS (Tech Sheet No. 16)

Description

Defective or missing seals on personnel doors contribute to air infiltration and should be repaired. The cost is minimal and the return can be great. Many different types of door seals are available, such as: rubber, nylon brush, bronze, felt, etc. No data are available to recommend any one type seal for personnel doors. One suggestion is to use a common seal for all personnel doors to take advantage of bulk purchase and common installation techniques.

Feasibility Requirements

Always feasible for heated hangars.

Survey Data Requirements

Average number of annual heating degree days; D_h , days-°F/yr

Procedure

Calculate the average AES from Figure 17 or as follows:

$$AES = 7.6 D_h \sqrt{5,700 + D_h}, \text{ Btu/yr}$$

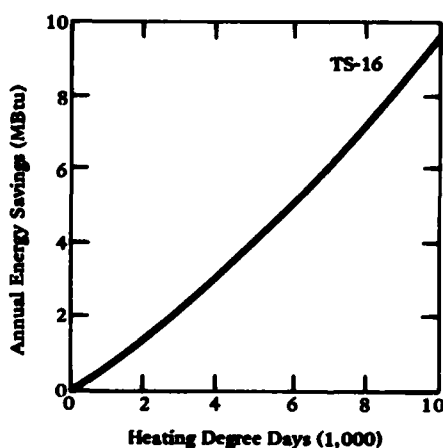


Figure 17. Annual energy savings for Tech Sheet No. 16.

General Information

Life: 5 years

Installation Cost: \$20/door

ENTRANCE VESTIBULE FOR PERSONNEL DOORS (Tech Sheet No. 17)

Description

When personnel doors are opened, heated inside air is displaced by cold outside air. Entrance vestibules limit the amount of heated air lost to the volume of the vestibule and also retard the rate of hot air displacement through open doors. In addition to saving energy, vestibules decrease drafts and serve as a shelter for people waiting on transportation, changing foul weather clothing, etc.

Feasibility Requirements

See Figure 18.

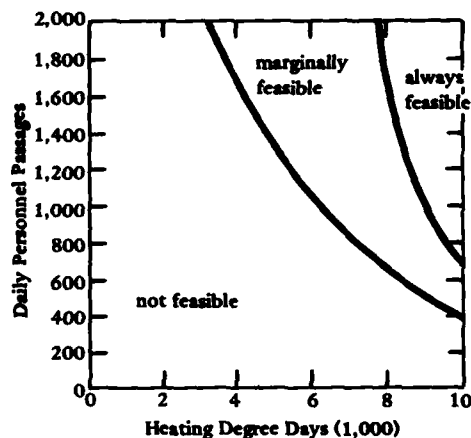


Figure 18. Feasibility requirements.

Survey Data Requirements

1. Average number of annual heating degree days; D_h , days-°F/yr
2. Average number of daily door openings; P_d , 1/day
3. Average time of each door opening; t , seconds
4. Door area; A , ft²

Procedure

Calculate the average AES from Figure 19 or as follows:

$$AES = 0.00043 D_h A P_d t (2.9 \sqrt{5,700 + D_h} - 1.5) 13,600 + D_h, \text{ Btu/yr}$$

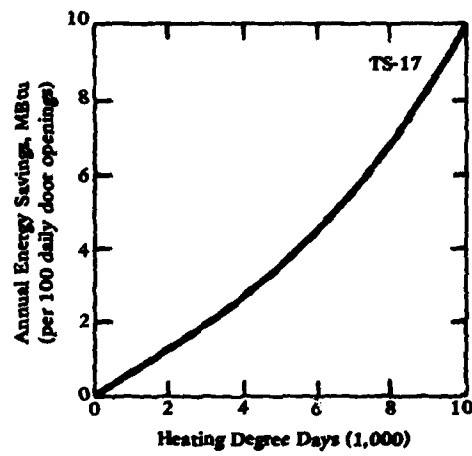


Figure 19. Annual energy savings for Tech Sheet No. 17.

General Information

Life: 25 years

Installation Cost: \$7,000/door

REVOLVING PERSONNEL DOORS (Tech Sheet No. 18)

Description

Revolving doors fitted to heavily used personnel access doors, which are not located in hangar aircraft or vehicle access doors, can reduce air infiltration. These doors are expensive and should be used in hangars that have very heavy personnel traffic.

Feasibility Requirement

See Figure 20.

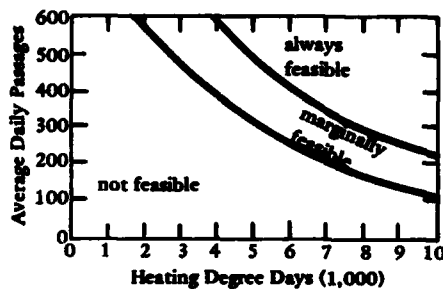


Figure 20. Feasibility requirements.

Survey Data Requirements

1. Average number of annual heating degree days, D_h , days-°F/yr
2. Average number of daily passages through door, P_p , 1/day

Procedures

Calculate the average AES from Figure 21 or as follows:

$$AES = 0.22 P_p D_h \sqrt{5,700 + D_h}, \text{ Btu/yr}$$

General Information

Life: 25 years

Installation Cost: \$6,500/door

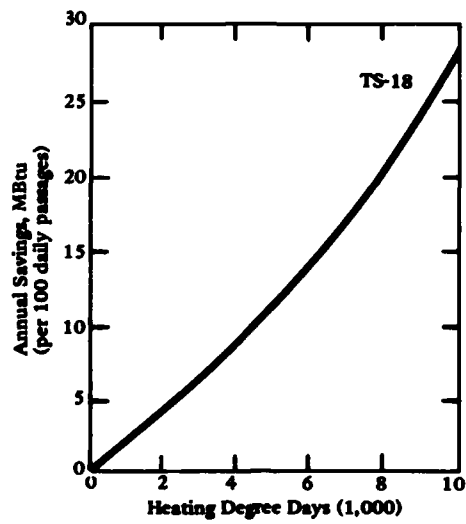


Figure 21. Annual energy savings for Tech Sheet No. 18.

LOADING DOCK SEALS (Tech Sheet No. 19)

Description

When trucks are loaded and unloaded at loading docks, large quantities of heated interior air is lost. Although few hangars have loading docks, many similar types of structures, such as warehouses, do. The installation of rubber seals around the perimeter of a loading dock door can reduce the amount of energy lost (Figure 22).

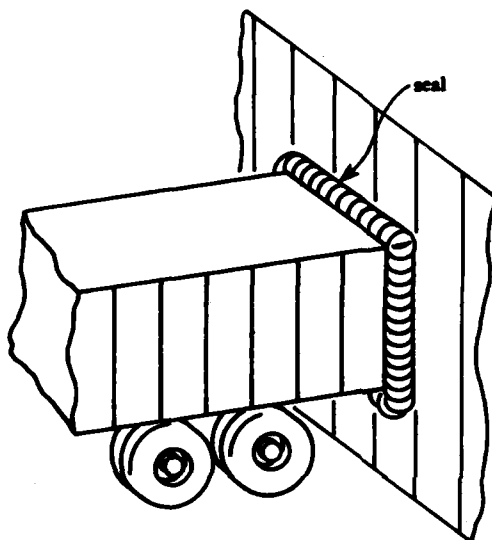


Figure 22. Loading dock seal.

Feasibility Requirements

See Figure 23.

Survey Data Requirements

1. Average number of annual heating degree days; D_h , days-°F/yr
2. Average number of hours per day loading dock door is open; P_h , hr/day

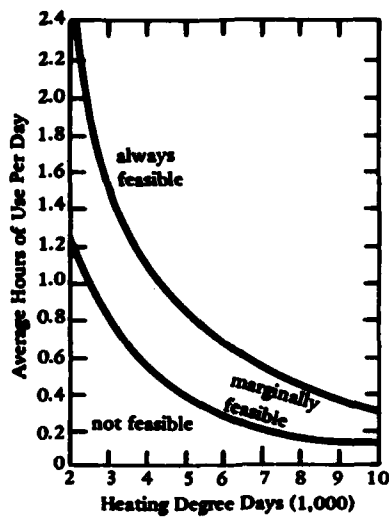


Figure 23. Feasibility requirements.

Procedure

Calculate the average AES from Figure 24 or as follows:

$$AES = 56 D_h P_h \sqrt{D + 5,700}, \text{ Btu/yr}$$

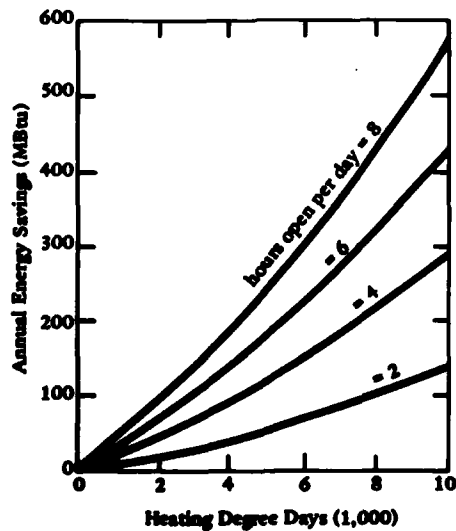


Figure 24. Annual energy savings for Tech Sheet No. 19.

General Information

Life: 5 years

Installation Cost: \$25.00/perimeter foot

HANGAR DOOR HEATING SYSTEM SHUTOFF SWITCH (Tech Sheet No. 20)

Description

When an aircraft enters or leaves a hangar the heated interior air is replaced by cold outside air. Dependent upon the outside air temperature and wind velocity between 2 to 10 minutes is required for all of the heated interior air to be displaced. Typical hangar heating systems operate continuously whenever the hangar doors are open. This heated air is rapidly displaced to the outside and lost. Significant amounts of energy can be saved by not operating the heating system when the hangar doors are opened. The hangar door shutoff switch should secure only the heating systems blower and not steam or hot water. In addition, a low temperature/time override control is required which will override the shutoff switches to prevent fire protection systems from freezing during prolonged door openings in very cold weather.

Feasibility Requirements

Always feasible for heated hangars.

Survey Data Requirements

1. Average number of annual heating degree days; D_h , days-°F/yr
2. Area of hangar door opened; A , ft²
3. Total average daily open time; P_h , hr/day

Procedure

Calculate the average AES from Figure 25 or as follows:

$$AES = 4.5 D_h A P_h \sqrt{D_h + 5,700}, \text{ Btu/yr}$$

General Information

Life: 15 years

Installation Cost: \$5,000/hangar

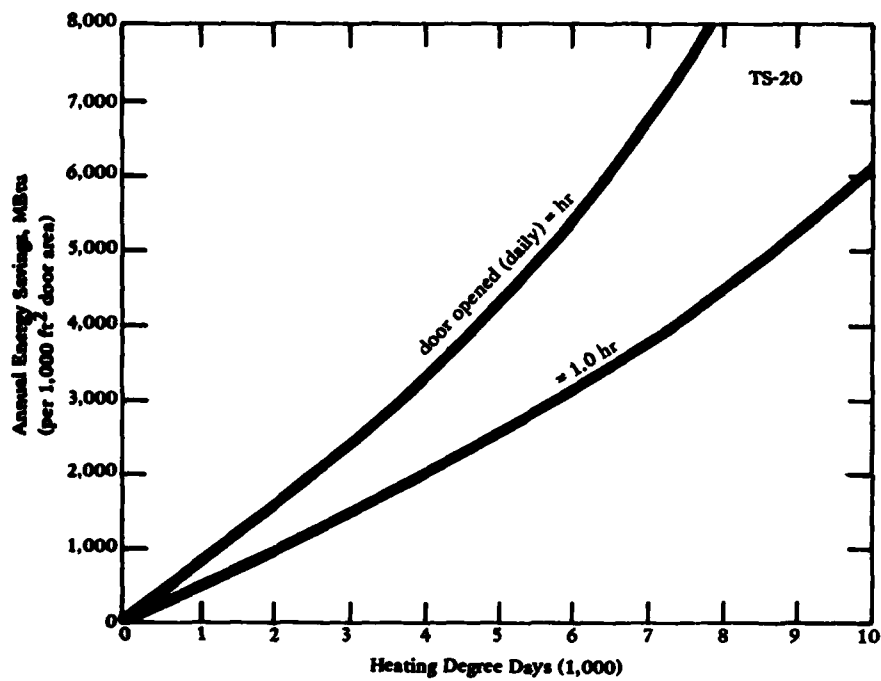


Figure 25. Annual energy savings for Tech Sheet No. 20.

TEMPERATURE SETBACK DEVICES (Tech Sheet No. 21)

Description

Working hours for many hangars are less than 24 hours per day. When daily non-work periods are 6 hours or more, temperature setback devices such as thermostats and time clocks can reduce hangar energy consumption. A temperature setback of 10°F is recommended. Temperature setback is not recommended for corrosion control hangars.

Feasibility Requirement

All heated hangars with daily non-work periods of 6 hours or more.

Survey Data Requirements

1. Daily hours of operation; H, hr/day
2. Average number of days in heating season; N/yr
3. Volume of hangar; V, ft³
4. Roof U value; U_r , Btu/ft² · °F-hr
5. Wall U value; U_w , Btu/ft² · °F-hr
6. Roof area; A_r , ft²
7. Wall area; A_w , ft²
8. Heating system efficiency; e, %±100
9. Difference between heating temperature and setback temperature; ΔT , °F

Procedure

Calculate the AES as follows:

$$\text{AES} = \Delta T N (2-4 H) (0.024 V + U_r A_r + U_w A_w) / e, \text{ Btu/yr}$$

General Information

Life: 15 years

Cost: \$300 to \$3,000/hangar

RADIANT HEATING (Tech Sheet No. 22)

Description

Radiant heaters emit heat in a straight, line of site, direction. Radiant heating is practical for applications where air infiltration rates are high (poor building design, frequent door openings, high ventilation requirements, etc.). Radiant heating uses infrared radiation. Air, the medium for conductive heat, is a poor absorber of infrared radiation and is not heated. Upon striking an object or person, this energy is converted into heat. Floors, walls, and other objects become warm and give off heat to the surrounding air.

Feasibility Requirements (Retrofit)

Marginally feasible: 2,000 heating degree days.

Always feasible: 3,500 heating degree days.

Survey Data Requirements

1. Average number of annual heating degree days; D_h , days-°F/yr
2. Extension surface area (walls and roof); A , ft²
3. Building volume; V , ft³

Procedure

Calculate the average AES from Figure 26 or as follows:

$$AES = D_h (A + 0.22 V) \text{ Btu/yr}$$

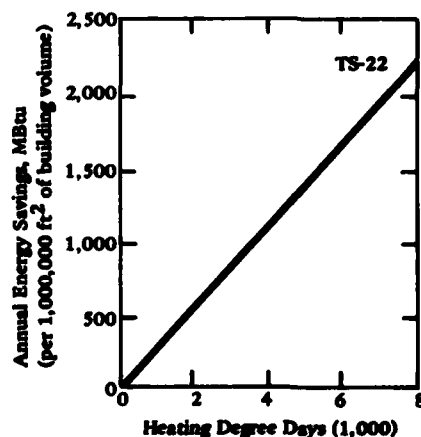


Figure 26. Annual energy savings for Tech Sheet No. 22.

General Information

Life: 25 years

Installation Cost: Site specific

BOILER TUNE UP (Tech Sheet No. 23)

Description

Many hangars and similar structures have on-site boilers for space heating (Figure 27). Boilers operate more efficiently if tuned up and adjusted annually. The boiler should be tuned up after the fire side surfaces have been cleaned, the fuel filters replaced, and the burner nozzles cleaned or replaced.

Feasibility Requirements

Always feasible.

Survey Data Requirements

1. Annual fuel consumption; G, gallons/yr
2. Type fuel (natural gas, No. 2 fuel oil, No. 6 fuel oil, JP-5, etc.)
3. Boiler combustion test kit
4. Handtools (screwdriver, wrenches, etc.)
5. Combustion efficiency calculation

Procedure

1. Measure flue gas temperature, percent of carbon dioxide, and smoke density then calculate boiler efficiency (e_1).
2. Adjust combustion controls/boiler draft to obtain highest percent of carbon dioxide in the flue gas while maintaining a smoke spot reading of one; calculate the boiler efficiency (e_2).
3. Calculate the average AES as follows:
$$\text{AES} = 150,000 \times G (e_2 - e_1), \text{ Btu/yr}$$

General Information

Life: One heating season
Cost: 2 manhours

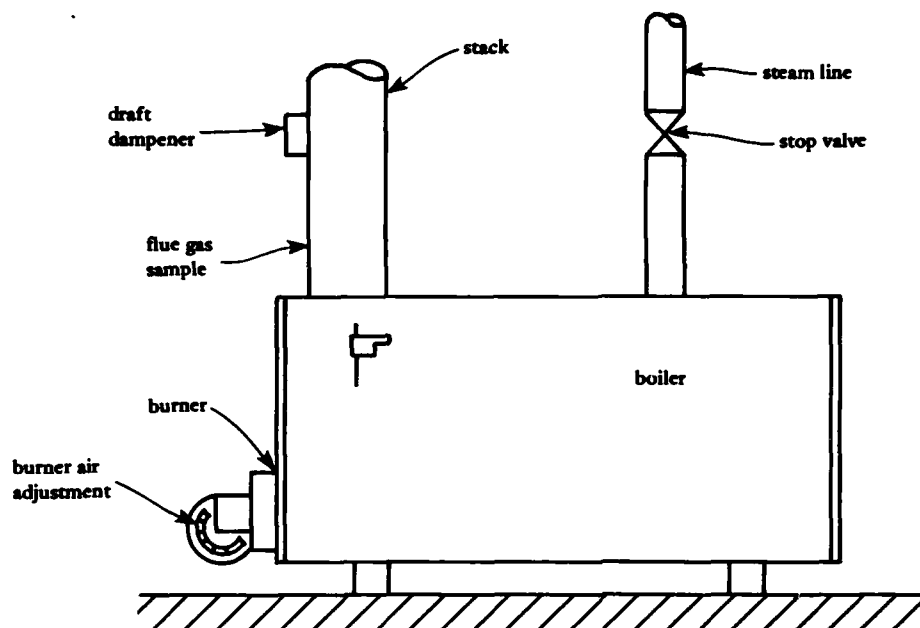


Figure 27. Boiler flue gas sample point.

LOW-WATTAGE FLUORESCENT LAMPS (Tech Sheet No. 24)

Description

Until recently lighting systems were oversized and produced excessive amounts of light. Most office spaces in hangars and other structures use fluorescent lamps and have excessive lighting levels. Replacing the existing fluorescent lamps with lower wattage lamps can save energy. This concept is feasible only if the low-wattage fluorescent lamps are used as part of a scheduled replacement program. For example, when a 50-watt fluorescent lamp needs replacing, use a 40-watt fluorescent lamp instead. The cost for the energy saving concept involves only the time required to identify lighting systems suitable for using low-wattage lamps. The actual cost should be no more than the normal cost of the replacement program.

Feasibility Requirements

Always feasible if done as part of the normal replacement program.

Survey Data Requirements

1. Number of fluorescent lamps; N
2. Number of hours used per year; H, hr/yr

Procedure

Calculate the average AES as follows:

$$\begin{aligned}\text{AES} &= 165 N H, \text{ Btu/yr, or} \\ &= 0.015 N H, \text{ kW-hr/yr}\end{aligned}$$

General Information

Life: Same as higher wattage lamps

Cost: \$0.21/lamp greater than higher wattage lamps

HIGH-PRESSURE SODIUM LIGHTING SYSTEM (Tech Sheet No. 25)

Description

Some hangars are not retrofitted with energy efficient lighting systems. High-pressure sodium lighting is one method to reduce electrical consumption in hangars.

Feasibility Requirements

Feasible for hangars with 40 or more hours of operation per week.

Survey Data Requirements

1. Number of hours in use annually; H, hr/yr
2. Number of light fixtures; N_f
3. Existing lamp wattage rating; W, watts

Procedure

Calculate the average annual energy savings (AES) as follows:

$$\text{AES} = 4 N H W, \text{ Btu/yr or}$$

$$\text{AES} = 0.00036 N H W \text{ kW-hr/yr}$$

COLD AIR JET HANGAR DESTRATIFIER (Tech Sheet No. 26)

Description

Measurements made in Navy and Air Force hangars indicated that stratification, the formation of a hot air pocket in the structure's ceiling, is a typical condition. Tests, conducted on commercial destratifiers, did not identify any units that were practical for use in hangars. A cold air jet destratifier, developed by the Naval Civil Engineering Laboratory, was successful and was able to reduce steam consumption in one hangar by 29%. The cold air jet transfers cold floor air and discharges it as a high-velocity jet at roof level, see Figure 28. Design considerations are provided in Appendix A.

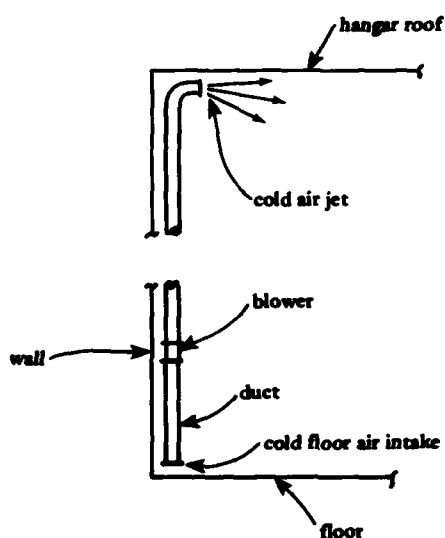


Figure 28. Coal-air jet destratifier.

Feasibility Requirements

See Figure 29.

Survey Data Requirements

1. Average number of annual heating degree days; D_h , days-°F/yr
2. Hangar floor area; A , ft²

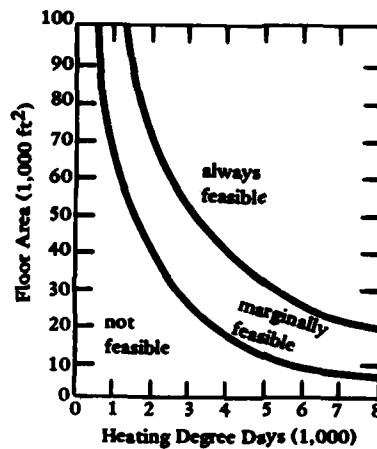


Figure 29. Feasibility requirements.

Procedure

Calculate the average AES from Figure 30 or as follows:

$$AES = 4.5 A D_h, \text{ Btu/yr}$$

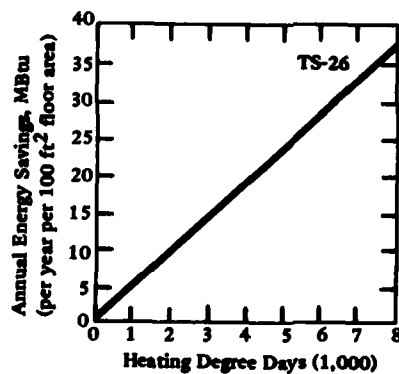


Figure 30. Annual energy savings for Tech Sheet No. 26.

General Information

Life: 25 years

Installation Cost: \$8,000 per unit (approximately 6 units required/hanger)

HANGAR DESTRATIFICATION: HEATING SYSTEM MODIFICATION (Tech Sheet No. 27)

Description

Most hangars use unit heaters mounted in the hangar's ceiling. These heaters are mounted at the lower level of the purlin in order to reduce the distance that they must blow heated air down to the floor. Unit heaters can be modified to recover some of the hot air trapped in the ceiling by running a duct from just below a hangar's roof to the unit heater's air intake, Figure 31. Since several different heating system and hangar designs have been used, the design of each heating system modification is site specific. The heating system modification is recommended for hangars with draft curtain "egg crate" sectionalized ceilings.

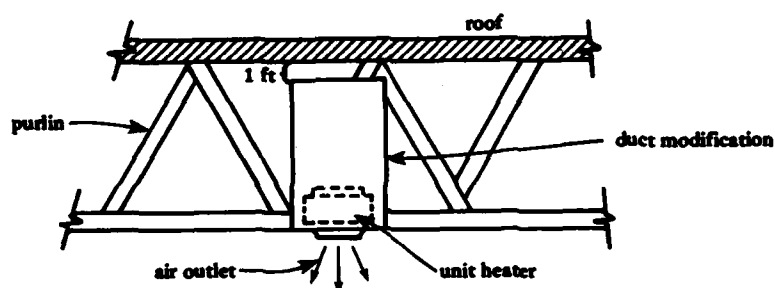


Figure 31. Heater duct modification.

Feasibility Requirements

(a) Marginally feasible: hangars with at least 12,000 ft² of floor area per unit heater located in geographic regions with at least 3,000 heating degree days.

(b) Always feasible: hangars with at least 16,000 ft² of floor area per unit heater located in geographic regions with at least 4,000 heating degree days.

Survey Data Requirements

1. Average number of annual heating degree days; D_h , days-°F/yr
2. Number of unit heaters in hangar; N
3. Hangar flow area; A , ft²

Procedure

Calculate the average AES from Figure 32 or as follows:

$$AES = 0.55 A D_h, \text{ Btu/yr}$$

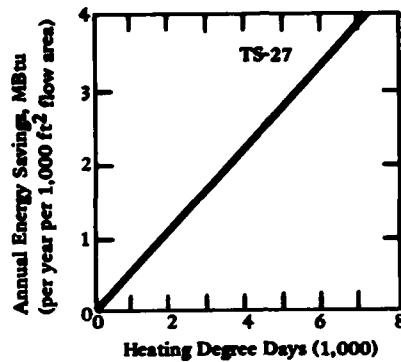


Figure 32. Annual energy savings for Tech Sheet No. 27.

General Information

Life: 25 years Installation Cost: \$4,000/unit heater

DESTRATIFICATION OF STRUCTURES WITH LOW CEILINGS (15-25 FEET) USING FLOOR LEVEL AIR BLOWERS (Tech Sheet No. 28)

Description

Floor level air blowers are used to blow cold air toward the ceiling where it is mixed with the hot ceiling air, Figure 33. Floor level blowers are an effective method to destratify shops, warehouses, etc., with ceilings lower than 25 feet, and where the destratifier units can be placed away from exterior walls. The cold air blower requires approximately 25 ft² of floor area. Fire detection can be delayed in the early stages of a slow starting fire (such as a smoldering cigarette in trash, etc.), for this reason, destratifiers are not recommended for use when the building is unoccupied. These destratifiers can be plugged directly into existing electrical power outlets.

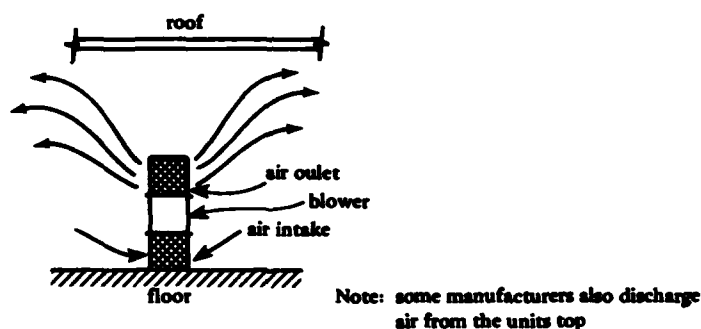


Figure 33. Floor level air blower.

Feasibility Requirement

Feasible for all heated structures with ceilings lower than 25 feet and floor space available for the units.

Survey Data Requirements

1. Average number of annual heating degree days; D_h , days-°F/yr
2. Building floor area; A , ft²

Procedure

Calculate the average AES from Figure 34 or as follows:

$$AES = 4.5 A D_h, \text{ Btu/yr}$$

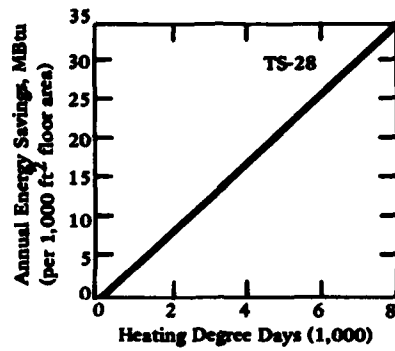


Figure 34. Annual energy savings for Tech Sheet No. 28.

General Information

Number of Units Required: floor area divided by 5,000
Installation Cost: \$20/100 ft² of floor area

DESTRATIFICATION OF STRUCTURES WITH LOW CEILINGS (15-25 FEET) USING CEILING FANS (Tech Sheet No. 29)

Description

Ceiling fans are used to mix the hot air pocket located in a structure's ceiling to provide a destratification effect (Figure 35). To be effective, these units must move large volumes of air and this often causes complaints of drafts, uneven temperatures, etc. Ceiling fans blow hot air to the floor where it mixes with the cooler air. Installation costs are site specific and depend on the amount of electrical circuits that must be installed. Ceiling fans could have an adverse effect upon some fire detection systems and are not recommended for use when buildings are unoccupied.

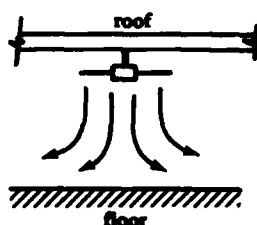


Figure 35. Ceiling fan.

Feasibility Requirement

Site specific. In general, they are feasible in structures where floor level temperatures are greater than 68°F and located in geographic regions with at least 2,000 heating degree days.

Survey Data Requirements

1. Average number of annual heating degree days, D_h , days-°F/yr
2. Building floor area; A , ft²

Procedure

Calculate the average AES from Figure 36 or as follows:

$$AES = 2 A D_h, \text{ Btu/yr}$$

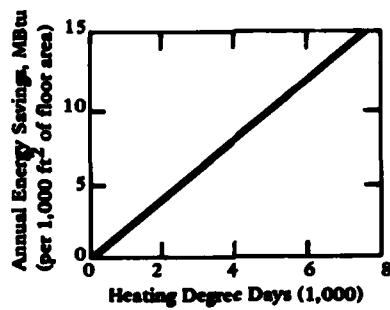


Figure 36. Annual energy savings for Tech Sheet No. 29.

General Information

Number of Fans Required, N ; $N = \text{floor area}/1,250$
 Installation Cost: \$1 ft² of floor area

DESTRATIFICATION OF STRUCTURES WITH LOW CEILINGS (15-25 FEET) USING DESTRATIFIER TUBES (Tech Sheet No. 30)

Description

The destratifier tube, Figure 37, is a small blower mounted on top of a tube or duct running from the ceiling to the floor. Hot ceiling air is transferred to the floor where it mixes with the cooler air. The effects that these tubes have on fire detectors is unknown; therefore, in the interest of safety, the destratifier tube should not be used during unoccupied periods of time, in unoccupied buildings, where personnel sleep, etc. The installation of destratifier tubes may require the installation of additional electrical circuits.

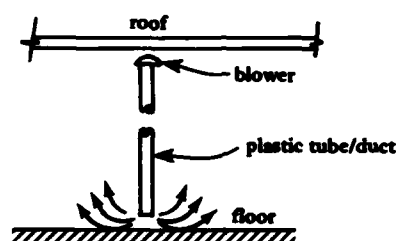


Figure 37. Destratification tube.

Feasibility Requirements

Site specific. In general, they are feasible in structures where floor level temperatures are greater than 68°F and located in geographic regions with at least 4,000 heating degree days.

Survey Data Requirements

1. Average annual heating degree days; D_h , days-°F/yr
2. Building floor area; A , ft²

Procedure

Calculate the average AES from Figure 38 or as follows:

$$AES = 0.25 A D_h, \text{ Btu/yr}$$

General Information

Number of Units Required; N ; $N = \text{floor area}/2,000$
Installation Cost: \$100/1,000 ft² of floor area

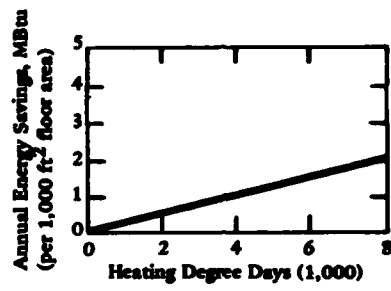


Figure 38. Annual energy savings for
Tech Sheet No. 30.

SECTION III - GENERAL AND ANNUAL ENERGY SAVINGS CALCULATIONS

The annual energy savings procedures used in the Tech Sheets provide a method to estimate the energy saved by various options. The procedures provide estimates to accurately rate energy conservation options and generate preliminary project documentation. This section provides procedures that can be used if additional accuracy is required to rate projects having similar costs and energy saving characteristics, or if local conditions greatly differ from the following assumptions that were used to generate the test sheet option procedures:

- (a) Average windspeed during heating season: 10 mph
- (b) Duration of heating season: 150 days
- (c) Overall heating plant efficiency: 70%
- (d) Hangar height: 40 feet

Tech Sheet No. 1: Exterior Surface Insulation (not applicable)

Tech Sheet No. 2: Seal Holes and Cracks in Walls and Doors

$$AES = \frac{26 D_h A}{e} \sqrt{79 v^2 H^{1/2} + 32 H D/N}$$

where: AES = annual energy savings, Btu/yr

D_h = annual number of heating degree days, days-°F/yr

A = area of crack or hole, ft²

e = overall heating system efficiency, %±100

v = average heating season windspeed, mph

H = building height, feet

N = number of days in heating season, days/yr

Tech Sheet No. 3: Seal Wall, Floor and Roof Cracks (same as Tech Sheet No. 2 except A = L W)

where: L = crack length, feet

W = average crack width, feet

Tech Sheet No. 4: Insulate Between Heated, Cooled, and Non-Heated Spaces (not applicable)

Tech Sheet No. 5: Reduce Window Area

$$AES = \frac{24 D_h A}{e} (U_p - U_f)$$

where: AES = annual energy savings, Btu/yr

D_h = number of heating degree days per yr, days-°F/yr

A = window area, ft²

U_p = existing U_{value} ; Btu/ft²-°F-hr

U_f = final U value, Btu/ft²-°F-hr

e = overall heating system efficiency, %÷100

Tech Sheet No. 6: Replace Broken and Missing Window (same as Tech Sheet No. 2)

Tech Sheet No. 7: Storm and Double-Glazed Windows (same as Tech Sheet No. 5)

Tech Sheet No. 8: Replace Window Seals (same as Tech Sheet No. 3)

Tech Sheet No. 9: Replace Missing Hangar Door Seals (same as Tech Sheet No. 2 except that A = 0.9 A)

Tech Sheet No. 10: Nylon Brush Door Seals

$$AES = \frac{7,000 D_h L U^{1.1215}}{e}$$

where: AES = annual energy savings, Btu/yr

v = average windspeed for heating season, mph

D_h = number of heating degree days per year, days-°F/yr

L = length of seal, feet

e = overall heating system efficiency, %÷100

Tech Sheet No. 11: Aircraft Appendage Seals for Aircraft Sheds (same as Tech Sheet No. 2)

Tech Sheet No. 12: Misaligned Hangar Doors (same as Tech Sheet No. 2)

Tech Sheet No. 13: Vehicle Access Doors (same as Tech Sheet No. 2 except that A = Area hangar door opening-Area of vehicle door opening)

Tech Sheet No. 14: Flexible Vinyl Strip Doors

$$AES = 1.44 P A D_h (30 v - v^{1.72})$$

where: AES = annual energy savings, Btu/yr

P = average hours flexible door is used per day, hr/day

A = area of flexible door, ft²

D_h = number of heating degree days per year, days-°F/yr

v = average windspeed during heating season, mph

Tech Sheet No. 15: Insulate Hollow Steel Personnel Doors (same as Tech Sheet No. 5)

Tech Sheet No. 16: Personnel Door Seals (same as Tech Sheet No. 2 except that A = 0.004L where L = door perimeter, feet)

Tech Sheet No. 17: Entrance Vestibules for Personnel Doors

$$AES = \frac{0.018 P D_h t}{60 e} \left(A_1 \sqrt{79 v^2 H_1^{1/2} + 32 H_1 D_h / N} - A_2 \sqrt{79 v^2 H_2^{1/2} + 32 H_2 D_h / N} \right)$$

where: AES = annual energy savings, Btu/yr

P = average number of personnel passages per day, 1/day

D_h = heating degree days per year, days-°F/yr

t = average door open time per personnel passage, sec

e = overall heating system efficiency, %÷100

A₁ = original door area, ft²

H₁ = height of hangar, feet

H₂ = height of vestibule, feet

v = average windspeed during heating season, mph

N = number of days in heating season, days/yr

Tech Sheet No. 18: Revolving Personnel Doors (same as Tech Sheet No. 17 except that

$$A_2 \sqrt{76 v^2 H_2^{1/2} + 32 H D_h / N} = V_d / S$$

where: V_d = total volume of revolving door, ft^3
 S = number of revolving door sections

Tech Sheet No. 19: Loading Dock Seals

$$\text{AES} = \frac{D A P}{e} \sqrt{79 v^2 H^{1/2} H D_h / N}$$

where: AES = annual energy savings, Btu/yr
 D_h = heating degree days per year, $\text{days-}^\circ\text{F/yr}$
 P = average hours in use per day, hr/day
 A = open area, ft^2
 e = heating system efficiency, $\% \div 100$
 v = average windspeed during heating season, mph
 H = building height, ft
 N = number of days in heating season, days/yr

Tech Sheet No. 20: Hangar Door Heating System Shutoff Switch (same as Tech Sheet No. 19 except that AES is zero if $V \geq Q$)

V = hangar volume, ft^3

$$Q = 60 A P \sqrt{79 v^2 H^{1/2} + 32 H D_h / N}, \text{ft}^3$$

Tech Sheet No. 21: Temperature SetBack Devices (not applicable)

Tech Sheet No. 22: Radiant Heating

$$\text{AES} = \frac{4.3 D_h}{e} \left[\sum A_s U_s + 0.018 I V \right], \text{Btu/yr}$$

where: AES = annual energy savings, Btu/yr
 D_h = heating degree days per year, $\text{days-}^\circ\text{F/yr}$
 e = heating system efficiency, $\% \div 100$
 A_s = exterior surface area, ft^2

U_s = U value of exterior surface, Btu/ft²-°F-hr

I = air infiltration rate, air changes per hour, 1/hr

V = building volume, ft³

Tech Sheet No. 23: Boiler Tune Up (not applicable)

Tech Sheet No. 24: Low-Wattage Florescent Lamps (not applicable)

Tech Sheet No. 25: High-Pressure Sodium Lighting Systems (not applicable)

Tech Sheet No. 26: Cold Air Jet Hangar Destratifier

$$AES = \frac{24 \epsilon N}{e} (T_c - T_f) (U_r A_r + 0.018 I V)$$

where: AES = annual energy savings, Btu/yr

N = number of days in heating season, days/yr

V = hangar volume, ft³

A_r = roof area, ft²

U_r = U value of roof, Btu/ft²-°F-hr

I = air infiltration rate, air changes per hour, 1/hr

ϵ = destratifier efficiency, %±100

ϵ = 0.9; cold jet and floor level air blower

ϵ = 0.11; heating system modification

ϵ = 0.40; ceiling fan

ϵ = 0.05; destratification tube

e = heating system efficiency, %±100

T_c = air temperature at ceiling level, °F

T_f = air temperature at floor level, °F

Tech Sheet No. 27: Hangar Destratification: Heating System Modification
(same as Tech Sheet No. 26)

Tech Sheet No. 28: Destratification of Structures With Low Ceilings
Using Floor Level Air Blowers (same as Tech Sheet No. 26)

Tech Sheet No. 29: Destratification of Structures With Low Ceilings
Using Ceiling Fans (same as Tech Sheet No. 26)

Tech Sheet No. 30: Destratification of Structures With Low Ceilings
Using Destratifier Tubes (same as Tech Sheet No. 26)

Appendix A
DESTRATIFIER PERFORMANCE CRITERIA

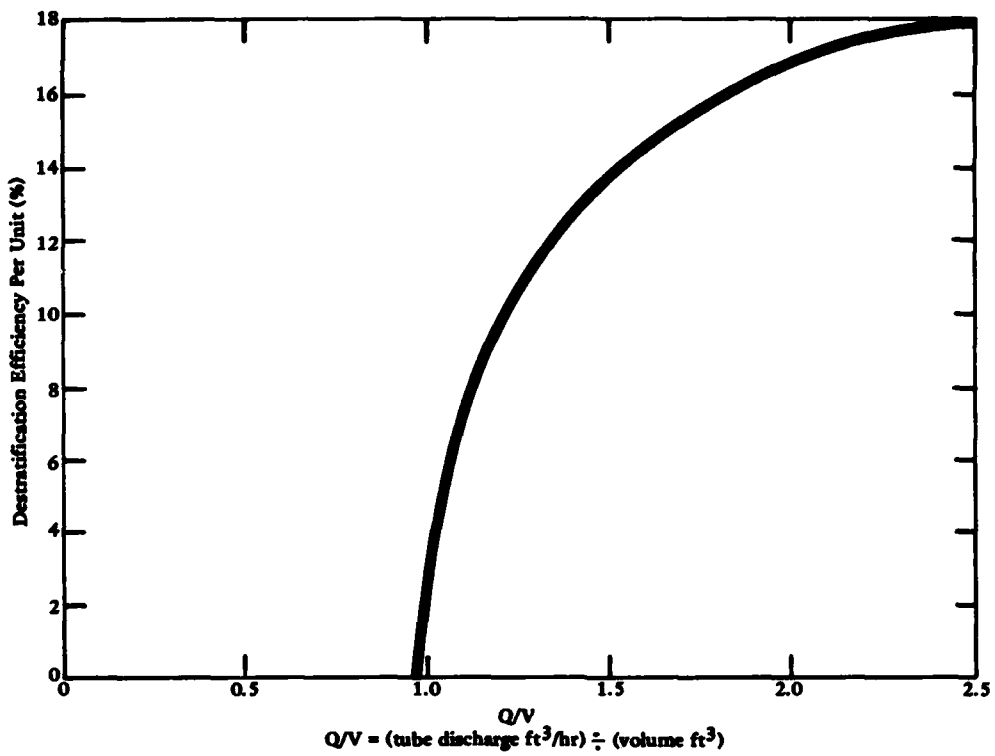


Figure A-1. Destratifier tube performance for building heights less than 25 feet.

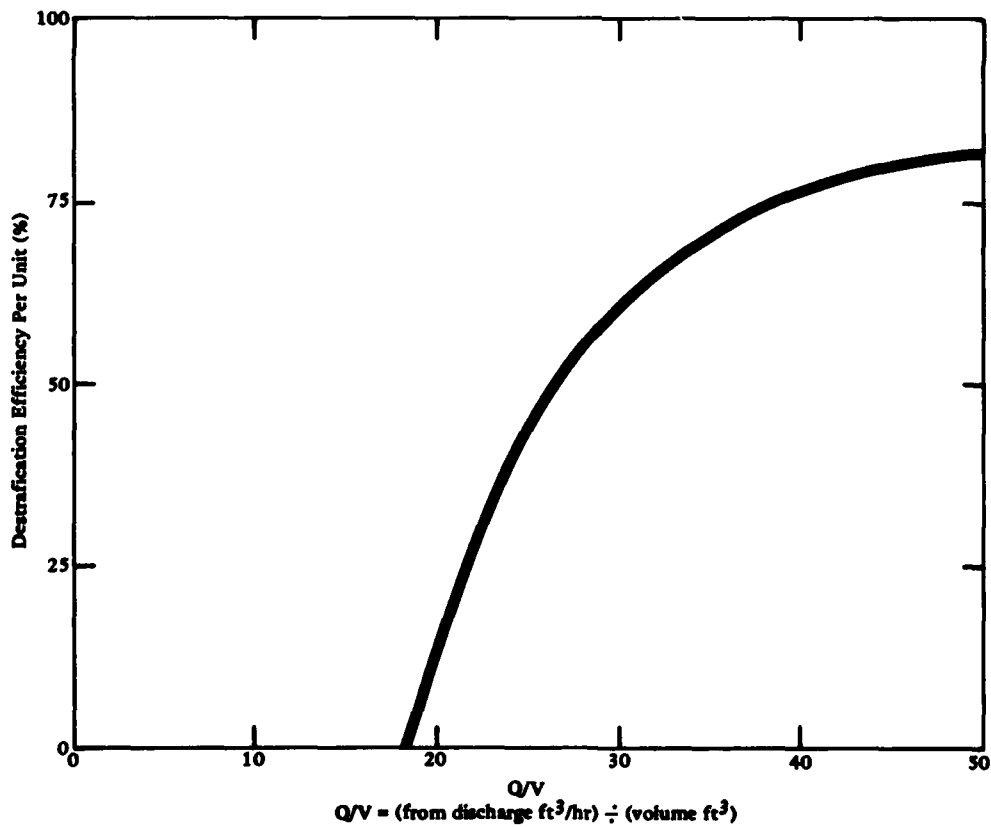
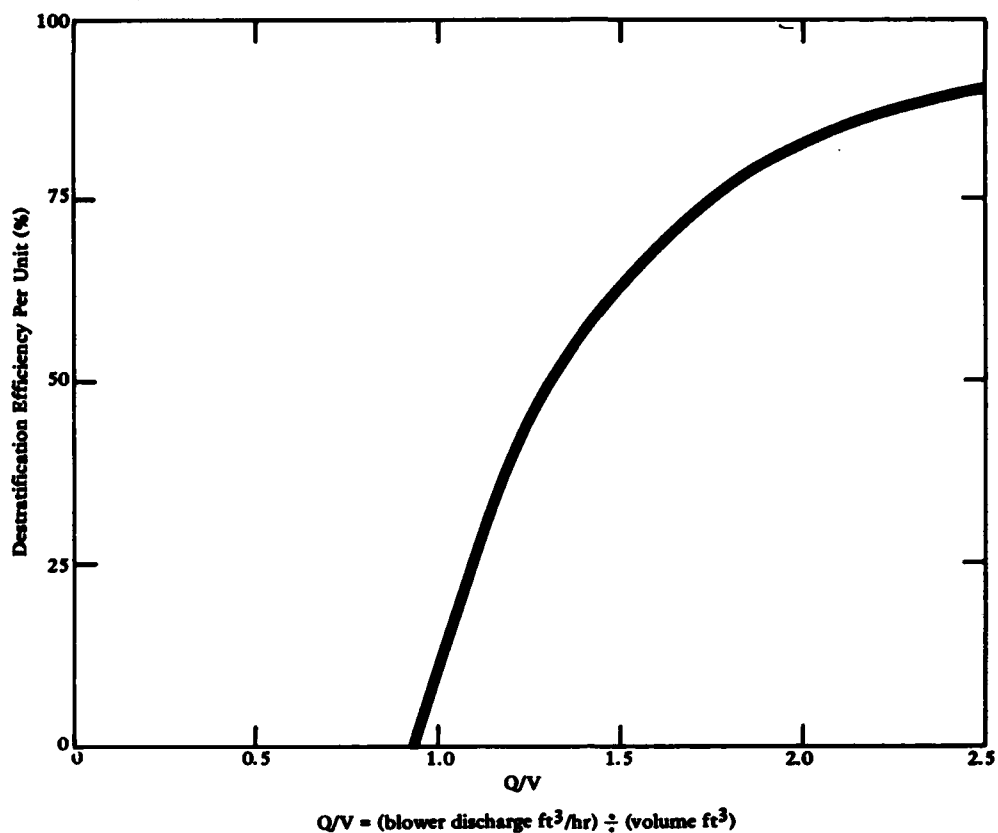


Figure A-2. Ceiling fan destratification performance for building heights less than 25 feet.



Cold Air Jet Destratifier Design Considerations

1. Destratifier flow: Q , ft^3/min

$$Q = 0.0027 V/N, \text{ ft}^3/\text{min}$$

V = hangar volume, ft^3

N = number of ceiling sections created by draft curtains or 6, whichever is greater

2. Destratifier air discharge velocity; U , ft/min

$$U = 641 W^2/Q, \text{ ft}/\text{min}$$

W = hangar width, ft

3. Destratifier nozzle diameter; D , in.

$$D = 24 (Q/(\pi U))^{1/2} \text{ in.}$$

Figure A-3. Floor air blower performance for building height less than 25 feet.

Appendix B
LIGHTING CRITERIA

RECOMMENDED LIGHTING LEVELS*

With proper attention to quality, the following light levels should be adequate for the areas cited:

- (A) Circulation areas between work stations: 20 footcandles
- (B) Background beyond tasks at circulation area: 10 footcandles
- (C) Waiting rooms and lounge areas: 10-15 footcandles
- (D) Conference Tables: 30 footcandles with background lighting
10 footcandles
- (E) Secretarial Desks: 50 footcandles with auxiliary localized (lamp) task lighting directed at paper holder (for typing) as needed. In secretarial pools, 60 footcandles.
- (H) Kitchens: Non-uniform lighting with an average of 50 footcandles
- (I) Cafeterias: 20 footcandles
- (J) Snack Bar: 20 footcandles
- (K) Testing Labs: As required by the task, but background not to exceed 3 to 1 ratio in footcandles.
- (L) Computer Rooms: As required by the task, (consider 2 levels: one-half and full). In computer areas, reduce general overall lighting levels to 30 footcandles and increase task lighting for critical areas for input. Too high a level of general lighting makes it difficult to read the self-illuminated indicators.
- (M) Drafting: 80 footcandles at full-time work station and 60 footcandles at part-time work stations.
- (N) Accounting Offices: 80 footcandles at work stations

*All levels are average ESI footcandles unless otherwise noted. Where applicable, refer to health and safety codes and Federal standards (OSHA) for minimum lighting specification.

The luminous efficacy (lumens per watt) of various light sources as compared to daylight are shown below (no allowance for ballast of luminaires):

Table B-1. Luminous Efficacy

Light Sources	lumens/watts
Low pressure sodium	183
Natural	120*
High pressure (HD)	105-120
Metal halide	85-100
Fluorescent	67-97
Mercury vapor	56-63
Incandescent	17-22

*Varies

Table B-2. Comparison of Mercury Vapor and High-Pressure Sodium Lamps

Mercury Vapor Lamp			High Pressure Sodium Lamp			Increased Lumens Per Lamp	Savings Per Lamp (watts)
Type	Total Watts Per Lamp	Lumen Output	Type	Total Watts Per Lamp	Lumen Output		
H33 (400w)	450	23,000	S50 (250w)	305	27,500	4,500	145
H37 (250w)	285	13,000	S55/56 (150w)	188	16,000	3,000	97
H39 (175w)	205	8,500	S54 (100w)	126	9,500	1,000	79

Appendix C
MATERIAL THERMAL PROPERTIES

Table C-1. U Values for Common Walls and Roofs

Description	U Value BTU/ft ² -°F
Walls	
1-inch stucco, air space, 3-inch insulation	0.083
Metal siding, 3-inch insulation, air space, metal	0.086
Surface finish, 3-inch insulation, surface finish	0.090
4-inch face brick, 2-inch insulation, 8-inch concrete block	0.100
1-inch stucco, 8-inch concrete, 1-inch insulation	0.198
Metal siding, 1-inch insulation, air space, metal	0.203
4-inch face brick, air space, 8-inch concrete block	0.237
4-inch lightweight concrete	0.240
4-inch face brick, air space, 4-inch common brick	0.335
1-inch stucco, air space	0.512
1-inch stucco, 8-inch heavy weight concrete	0.585
Roofs	
Roof terrace, acoustic ceiling	0.084
2-inch insulation, 1-inch wood, air space, acoustic ceiling	0.085
2-inch insulation, metal deck, air space, acoustic ceiling	0.095
2-inch insulation, 2-inch wood	0.112
1-inch insulation, 1-inch wood, air space, acoustic ceiling	0.120
2-inch insulation, 4-inch heavy weight concrete	0.124
1-inch insulation, 1-inch wood, air space, acoustic ceiling	0.129
4-inch lightweight concrete, air space, acoustic ceiling	0.140
4-inch lightweight concrete, air space, acoustic ceiling	0.140
1-inch insulation, 1-inch wood	0.180

Table C-2. Thermal Conductivity (k) of Industrial Insulation (Design Values)
(for Mean Temperatures Indicated)

[Expressed in Btu per (hour) (square foot) (degree Fahrenheit)
temperature difference per inch]

Form/Material Composition	Typical Density (lb/ft ³)	Typical Conductivity k at Mean Temp F				
		0	25	50	75	100
BLOCKS, BOARDS, AND PIPE INSULATION ASBESTOS						
Laminated asbestos paper	30					0.40
Corrugated and laminated asbestos paper						
4-ply	11-13				0.54	0.57
6-ply	15-17				0.49	0.51
8-ply	18-20				0.47	0.49
MOLDED AMOSITE AND BINDER	15-18					0.32
85% MAGNESIA	11-12					0.35
CALCIUM SILICATE	11-13					0.38
CELLULAR GLASS	9	0.35	0.36	0.38	0.40	0.42
DIATOMACEOUS SILICA	21-22					

(Continued)

Table C-2. Continued

Form/Material Composition	Typical Density (lb/ft ³)	Typical Conductivity k at Mean Temp F				
		0	25	50	75	100
MINERAL FIBER						
Glass						
Organic bonded, block, and boards	3-10	0.20	0.22	0.24	0.25	0.26
Nonpinking binder	3-10					0.26
Pipe insulation, slag or glass	3-4	0.20	0.21	0.22	0.23	0.24
	3-10	0.20	0.22	0.24	0.25	0.26
Inorganic bonded block	10-15					0.33
	15-24					0.32
Pipe insulation slag or glass	10-15					0.33
MINERAL FIBER						
Resin binder	15	0.25	0.26	0.28	0.29	
RIGID POLYSTYRENE						
Extruded, Refrigerant 12 exp	3.5	0.16	0.17	0.18	0.19	0.20
Extruded, Refrigerant 12 exp	2.2	0.17	0.18	0.19	0.20	
Extruded	1.8	0.21	0.23	0.24	0.25	0.27
Molded beads	1	0.25	0.25	0.26	0.28	
POLYURETHANE						
Refrigerant 11 exp	1.5-2.5	0.18	0.17	0.16	0.16	0.17
RUBBER, Rigid Foamed						
	4.5		0.20	0.21	0.22	0.23
VEGETABLE AND ANIMAL FIBER						
Wool felt (pipe insulation)	20		0.28	0.30	0.32	0.33

(Continued)

Table C-2. Continued

Form/Material Composition	Typical Density (lb/ft ³)	Typical Conductivity k at Mean Temp F				
		0	25	50	75	100
INSULATING CEMENTS						
Mineral Fiber (Rock, slag, or glass)	24-30 30-40					0.49 0.75
With colloidal clay binder With hydraulic setting binder						
LOOSE FILL						
Cellulose insulation (milled pulverized paper or wood pulp)	2.5-3			0.26	0.27	0.29
Mineral fiber, slag, rock or glass	2-5	0.23	0.25	0.26	0.28	0.31
Perlite (expanded)	5-8	0.32	0.34	0.34	0.37	0.39
Silica aerogel	7.6	0.15	0.15	0.16	0.17	0.18
Vermiculite (expanded)	7-8.2	0.42	0.44	0.45	0.47	0.49
	4-6	0.38	0.40	0.42	0.44	0.46

$$U \text{ Value} = \frac{K \text{ Value}}{\text{Insulation Thickness (in.)}}$$

Appendix D
WEATHER DATA

Weather Data

State/City	Winter		Summer	
	Avg. DB Winter Temp	Length In Weeks	Avg. DB Summer Temp	Length In Weeks
ALABAMA				
Birmingham	41.9	16.6	80.6	32.9
Montgomery	43.5	14.1	81.1	35.3
Huntsville	40.3	18.8	80.5	30.9
Mobile	44.7	10.4	79.4	38.4
ARIZONA				
Tucson	46.2	12.4	83.5	40.1
Flagstaff	35.6	33.4	73.5	18.6
Phoenix	46.4	11.4	86.0	41.3
ARKANSAS				
Blytheville	39.5	20.4	80.5	29.7
Little Rock	41.7	18.1	81.6	31.3
Ft. Smith	40.5	18.0	81.0	30.5
CALIFORNIA				
Los Angeles	50.2	8.9	72.0	32.6
San Diego	50.5	7.0	70.9	29.8
Santa Barbara	49.6	23.9	69.7	12.2
Bishop	40.2	21.3	82.2	30.4
Barstow	42.6	20.6	83.7	32.3
San Francisco	48.2	18.4	71.1	22.2
Sacramento	46.1	19.4	79.9	28.4
COLORADO				
Denver	35.2	29.4	77.9	22.6
Colorado Springs	35.4	30.4	76.9	21.6
Trinidad	36.2	27.7	78.5	25.4
Grand Junction	36.3	27.5	80.3	23.7
DELAWARE				
Dover	38.4	25.2	77.5	23.6
Wilmington	38.2	26.0	77.5	23.7

(Continued)

Weather Data				
State/City	Winter		Summer	
	Avg. DB Winter Temp	Length In Weeks	Avg. DB Summer Temp	Length In Weeks
FLORIDA				
Pensacola	44.7	10.4	79.4	38.4
Miami	49.3	1.6	80.4	50.1
Jacksonville	45.6	8.6	80.4	41.6
Orlando	48.5	3.0	78.5	46.2
Tampa	47.0	4.0	78.5	46.0
GEORGIA				
Atlanta	41.1	19.8	78.7	30.0
Augusta	42.6	16.0	80.7	35.1
Macon	43.3	14.5	80.3	34.8
Valdosta	45.0	10.7	80.0	38.9
Savannah	44.0	12.0	80.0	38.0
IDAHO				
Boise	38.1	31.4	78.8	19.7
Pocatello	35.1	33.3	78.6	18.8
Lewiston	40.2	29.7	78.8	18.9
ILLINOIS				
Chicago	34.2	30.0	77.0	20.9
Champaign	33.3	27.3	77.9	23.6
Peoria	34.0	26.0	78.0	24.0
Rockford	32.0	29.0	77.0	21.0
INDIANA				
Fort Wayne	34.8	28.5	77.7	22.5
South Bend	34.2	29.1	77.1	21.4
Indianapolis	35.8	26.7	78.0	23.9
Terre Haute	36.8	26.2	78.7	24.8
IOWA				
Mason City	29.8	31.1	76.7	19.7
Sioux City	31.2	28.9	79.0	22.2
Council Bluffs	32.1	27.2	78.5	23.0

(Continued)

Weather Data				
State/City	Winter		Summer	
	Avg. DB Winter Temp	Length In Weeks	Avg. DB Summer Temp	Length In Weeks
KANSAS				
Dodge City	35.9	25.4	81.4	25.6
Goodland	34.3	29.1	81.0	23.6
Kansas City	36.5	23.6	80.5	25.7
Wichita	37.0	22.6	81.2	27.0
KENTUCKY				
Louisville	38.4	23.5	79.9	26.6
Covington	36.8	25.1	78.2	24.4
Hopkinsville	38.2	22.0	79.7	28.4
LOUISIANA				
New Orleans	46.4	9.4	79.8	39.6
Alexandria	43.7	13.3	81.0	37.2
Shreveport	42.6	15.2	81.8	35.2
Lake Charles	45.5	10.4	80.4	39.2
MAINE				
Portland	34.5	33.7	74.4	15.1
MASSACHUSETTS				
Boston	35.1	31.1	76.0	19.8
Springfield	34.6	30.5	76.3	20.1
MICHIGAN				
Lansing	34.0	30.4	76.0	19.5
Grand Rapids	34.4	30.5	75.0	19.0
Traverse City	33.0	32.8	75.3	17.0
Sault Ste Marie	30.2	37.0	73.4	12.8
Detroit	33.8	30.5	75.8	19.2
MINNESOTA				
Duluth	28.0	37.0	73.5	12.7
International Falls	25.5	36.8	73.8	14.1
Minneapolis	29.3	31.0	76.8	18.8

(Continued)

Weather Data				
State/City	Winter		Summer	
	Avg. DB Winter Temp	Length In Weeks	Avg. DB Summer Temp	Length In Weeks
MISSISSIPPI				
Biloxi	45.2	10.1	79.8	37.6
Jackson	43.0	14.8	81.1	35.3
Columbus	41.6	16.9	81.2	33.8
MISSOURI				
Kansas City	36.5	23.6	80.5	25.7
Columbia	36.1	24.4	80.2	25.7
Springfield	36.7	23.4	79.6	26.9
St. Louis	36.1	24.2	79.6	26.3
MONTANA				
Billings	34.6	32.1	78.1	18.4
Glasgow	27.9	33.5	77.8	17.5
Helena	32.9	36.0	76.1	15.5
Great Falls	33.8	33.8	76.6	16.9
NEBRASKA				
Omaha	32.1	27.2	78.5	23.0
Grand Island	32.6	28.6	79.4	22.7
North Platt	32.4	29.7	79.1	22.0
NEVADA				
Las Vegas	43.7	15.6	86.6	35.4
Ely	33.4	35.0	77.7	20.2
Winnemucca	36.2	31.9	80.4	22.3
Reno	35.0	33.0	79.0	21.0
NEW HAMPSHIRE				
Manchester	32.0	32.0	75.0	19.0
NEW JERSEY				
Trenton	37.5	26.9	77.1	22.9

(Continued)

Weather Data				
State/City	Winter		Summer	
	Avg. DB Winter Temp	Length In Weeks	Avg. DB Summer Temp	Length In Weeks
NEW MEXICO				
Albuquerque	39.7	23.9	80.4	27.3
Alamogordo	41.0	19.2	81.8	32.5
Clovis	38.7	23.1	79.9	29.4
NEW YORK				
Albany	33.8	30.5	76.4	19.5
Buffalo	34.5	31.1	75.0	18.8
Syracuse	34.0	30.2	76.1	19.4
New York City	38.0	27.5	76.0	20.0
NORTH CAROLINA				
Greensboro	40.1	21.6	79.0	28.1
Raleigh	41.0	20.0	79.0	30.0
Wilmington	43.6	15.2	78.5	33.6
NORTH DAKOTA				
Bismarck	27.4	33.5	77.8	18.3
Grand Forks	24.6	34.4	76.1	16.9
Minot	27.2	34.7	76.4	16.2
Fargo	27.2	35.0	77.0	17.0
OHIO				
Cleveland	34.0	29.4	76.5	21.0
Dayton	36.2	25.4	78.4	24.3
Columbus	37.8	25.5	77.6	23.8
Toledo	33.8	29.5	76.8	21.3
Cincinnati	36.8	25.1	78.2	24.2
OKLAHOMA				
Altus	39.5	19.5	83.2	31.2
Oklahoma City	38.9	20.0	81.2	29.5
Tulsa	39.0	20.2	81.7	29.7
Enid	37.9	21.6	81.9	28.4

(Continued)

Weather Data				
State/City	Winter		Summer	
	Avg. DB Winter Temp	Length In Weeks	Avg. DB Summer Temp	Length In Weeks
OREGON				
Burns	35.7	36.3	76.5	17.3
Medford	41.9	30.9	78.7	21.2
Pendleton	40.1	29.9	78.1	20.0
Portland	44.0	30.8	73.5	15.8
Eugene	44.0	30.8	74.0	15.0
PENNSYLVANIA				
Pittsburg	35.1	28.2	76.0	21.9
Scranton	35.2	29.7	76.2	20.1
Williamsport	36.4	28.9	77.2	21.0
Philadelphia	38.2	26.0	77.5	23.7
RHODE ISLAND				
Providence	37.6	28.8	74.7	18.7
SOUTH CAROLINA				
Charleston	43.3	14.2	78.7	36.0
Columbia	43.2	16.0	79.7	33.4
Myrtle Beach	43.0	15.9	77.9	32.3
SOUTH DAKOTA				
Rapid City	32.6	30.7	78.8	19.6
Huron	28.5	31.4	78.9	20.4
Sioux Falls	29.2	30.4	78.0	20.5
TENNESSEE				
Memphis	40.5	18.9	81.1	30.4
Nashville	39.3	23.3	79.7	28.4
Knoxville	39.5	21.5	80.0	29.0

(Continued)

Weather Data				
State/City	Winter		Summer	
	Avg. DB Winter Temp	Length In Weeks	Avg. DB Summer Temp	Length In Weeks
TEXAS				
Amarillo	38.1	23.0	80.4	28.4
Lubbock	39.1	20.8	80.3	30.8
Dallas	42.5	15.1	82.8	34.6
San Antonio	46.0	8.9	82.7	41.3
Corpus Christi	48.1	4.8	80.3	43.0
Houston	47.0	6.0	80.3	42.0
UTAH				
Salt Lake City	36.5	30.2	79.0	19.9
Wendover	36.7	27.7	79.7	21.6
VERMONT				
Burlington	31.3	33.1	74.8	16.7
VIRGINIA				
Richmond	40.9	20.9	77.8	26.8
Roanoke	39.8	23.4	78.9	26.3
WASHINGTON				
Seattle	43.7	37.3	70.9	9.4
Spokane	36.6	34.8	76.1	15.6
WEST VIRGINIA				
Charleston	38.4	23.7	78.4	26.1
Clarksburg	36.5	29.1	75.2	22.5
WISCONSIN				
Madison	31.5	30.7	76.9	20.2
Green Bay	31.1	33.0	75.2	17.5
Milwaukee	33.0	30.0	77.0	20.9
WYOMING				
Casper	33.6	33.5	78.3	19.2
Cheyenne	34.4	33.9	76.0	18.3
Rock Springs	31.7	35.3	75.3	16.7

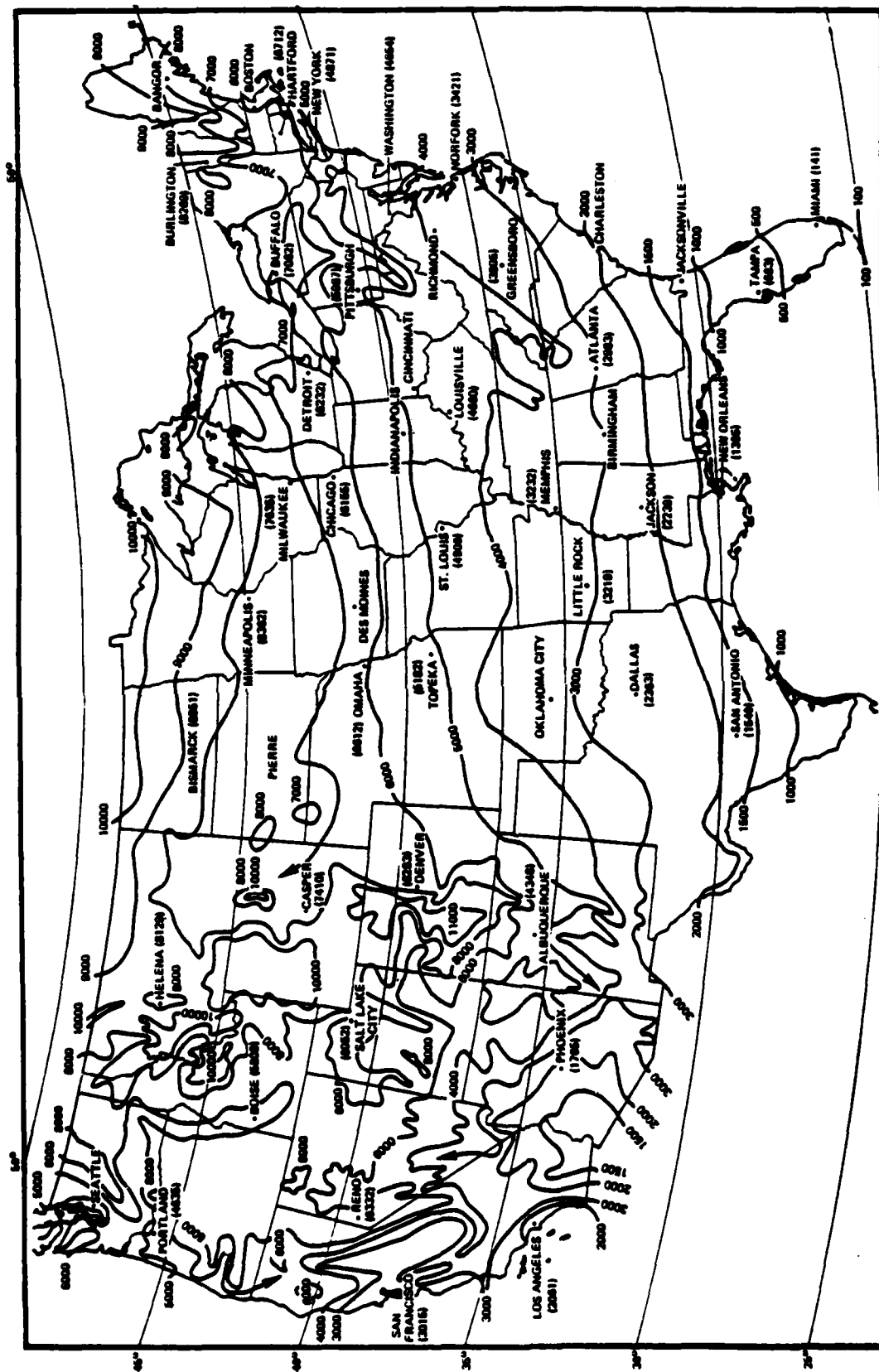


Figure D-1. Annual heating degree days (base 65°F).

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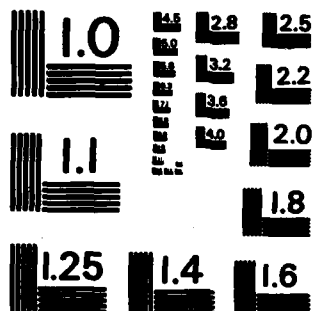
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